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TECHNICAL REPORT LWL-CR-12P72

LOCATION OF ARTILLERY MUZZLE FLASHES AT NIGHT
USING TERRESTRIAL PHOTOGRAMMETRY

by

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January 1974

Final Report

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report LWL-CR-12P72	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Location of Artillery Muzzle Flashes at Night Using Terrestrial Photogrammetry		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. G. Stephan, Battelle Memorial Institute, Columbus, Ohio 43201 Jacob Wenig & H. Clay McDowell, USALWL		8. CONTRACT OR GRANT NUMBER(s) F33657-71-C-0529
9. PERFORMING ORGANIZATION NAME AND ADDRESS Tactical Technology Center, Battelle Memorial Institute, Columbus, Ohio 43201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS LWL Task 12-P-72
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Land Warfare Laboratory Aberdeen Proving Ground, MD 21005		12. REPORT DATE January 1974
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES TECHNICAL LIBRARY BLDG. 805 ABERDEEN PROVING GROUND, MD. STEAP-TL		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The feasibility of photogrammetrically locating the position of artillery pieces by infrared photography of the muzzle flash was considered. An initial test was conducted simulating the muzzle flash with a light bulb. Two field tests were conducted with actual gun firings - one at Ft. Sill, OK, and one at Aberdeen Proving Ground, MD. A TV camera system with a response extending to the near IR is recommended as a convenient real-time sensor for artillery flash which should be usable for both day and night detections.		

AD-776379

PREFACE

This study was conducted under Contract No. F33657-71-C-0529 sponsored by the Defense Advanced Research Projects Agency and was funded by the U. S. Army Land Warfare Laboratory under Modification P00006.

This report represents a limited (less than 80 man-hour) effort in response to a specific question and is not intended to be a definitive report on this particular subject area.

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LOCATION OF ARTILLERY MUZZLE FLASHES AT NIGHT USING TERRESTRIAL PHOTOGRAMMETRY

by
J. G. Stephan

SUMMARY

A search of the TACTEC file for information on the use of photography to locate artillery muzzle flashes at night revealed no information that could be immediately applied to the problem. However, our knowledge of photogrammetry, photography, and the spectral characteristics of muzzle flashes permits us to say that such a technique is entirely feasible, provided some field test is performed to provide the data necessary for the refinement of hardware and techniques which will give a predetermined accuracy. A test was conducted using Polaroid and high-speed infrared film to determine whether a high-speed panchromatic or a high-speed infrared film should be used for exposures of up to 1/2 hour at night. It was determined that infrared film detects light sources at night at least 2 to 5 times better than the Polaroid film with an ASA of 400.

STATEMENT OF PROBLEM

Cameras are to be used to aid in the location or "fixing" of artillery firing infrequently at night. The question at hand is twofold: (1) what type of camera and film/filter combination would best detect muzzle flashes at night up to 10 miles from the camera? and (2) how sensitive would such a setup be in determining the location of such muzzle flashes?

DISCUSSION

There are a number of "fast" films on the market which could be used for the required photography. Only black-and-white film should be considered. Colored film requires as much as 5 times longer processing time than black and white. Polaroid film should also be a good, quick method of obtaining an image, however there may be some objection to its use because of its lack of resolution when compared to Plus-X film, for example.

The use of oblique terrestrial photography for mapping or target-locating purposes has long been established. As in all photogrammetric problems, the accuracy of measurements through photography depends on the sophistication of the equipment and techniques applied to the problems. To achieve the ultimate in accuracy, much importance must be placed on determining and maintaining the internal geometry of the camera, as well as upon establishing a minimum of ground control. Uncertainty about such parameters as the camera focal length, flatness of the film plane, lens distortion, or the orientation of the camera will result in a corresponding lack of target-location accuracy.

If the approach to the problem is to be fairly straightforward, using small noncalibrated cameras stationed only a few feet above the ground, then accuracies will probably be measured in thousands of feet. If some care is given to the selection of camera/film combination and equipment setup, the accuracies involved will probably be measured in hundreds of feet and better.

Suggested Equipment

Most of the equipment and films suggested here are readily available from commercial sources.

Cameras

Ideally, large-format cartographic cameras should be used, with a typical format of 240 x 240 mm and a focal length of 150 or 300 mm. Terrestrial cameras such as the Wild Phototheodolite, which combines a T-2 theodolite with a plate camera on a common axis, would also be an excellent choice. However, 4 x 5-in. and 35-mm cameras should also be tested, especially if the targets to be located may be a lot closer to the observer than the suggested 10 miles. Only quality cameras should be used here, however, such as Leica, Honeywell Pentax, Nikon, or Hasselblad. Some of these nonmetric cameras may have an electric drive which would be a desirable feature if observations are to be made throughout the night. Cartographic and reconnaissance cameras all have electrical drives but typically do not have a mechanism which permits opening of the shutter for periods any longer than 1/50 second. Some modification would therefore be necessary to facilitate their use.

Films

Any fast panchromatic film, such as Kodak Plus-X (ASA 125) or Tri-X (ASA 400), may be used. The slower black-and-white films should not be used, but an excellent film to be tested would be the high-speed IR film Type 2481 (tungsten rating of 200). The advantage of using an IR film over a panchromatic film is its increased spectral sensitivity. Panchromatic films have their greatest sensitivity in the visible range of the electromagnetic spectrum between 3500 and 7500 angstroms; IR film is sensitive out to 9500 angstroms.

Filters

A field test should determine whether the use of filters is required. Since filters almost always reduce the amount of light entering the camera lens, and since the use of filters is mostly required for daytime lighting conditions, it probably will not be desirable or necessary to use any filters.

Camera Mounts

It is very important that the photographic camera be firmly anchored during long hours of photographic exposure in order to eliminate any motion or vibration. Heavy camera or theodolite tripods should be used. Conceivably, even an artillery piece could be suitable. Theodolite tripods are very desirable since they have pointed metal spikes which can be driven into the ground.

Camera Setup

Two methods are suggested for camera setup: (1) the single camera used in conjunction with a perspective grid or Canadian grid, and (2) two identical cameras used like a surveyor's transit to measure the angles of a triangle in which the base distance between the camera and the inner orientation of the photographic camera is known.

With either method it is advisable to locate two or three light sources on aiming stakes some distance from the cameras which could be used as a means to check whether the camera orientation has changed between the initial and final moments of photographic exposure. They would also provide an additional means of ground control.

Perspective Grid Method

A single camera may be used, however the use of two cameras will result in greater accuracy. The camera(s) should be elevated as high as possible - on a tall building, a hill, or other elevated feature - the higher the better. Photographs should then be taken during the day to establish (1) the perspective grid (which may be sketched on an overlay) and (2) the accuracy of the grid by measuring the distances of visible landmarks on a large-scale topographic map. This method should only be attempted on relatively flat terrain. Map scales should not be smaller than 1:25,000. If the camera is then left undisturbed for nighttime exposures [as checked against the two or three control markers put into the foreground some distance from the camera(s)], then the grid established during the day will apply for the photography obtained during the night, permitting direct and immediate measurements.

Required for this method are:

- (1) Visibility of the image horizon in the photo (hence also the daylight photography)
- (2) Camera altitude
- (3) Camera focal length.

The grid is then drawn by:

- (1) Determination of the lens horizon on which the vanishing points fall.
- (2) Establishment of the perspective grid.

Figure 1 should be used in conjunction with the following instructions.

The principal point, P, is found by connecting opposite fiducial marks (the distance halfway between the four corners of each photograph). The intersection defines the principal point. A line is then drawn through the principal point, perpendicular to the apparent horizon (where earth and sky seem to merge). This is the principal line. Where it intersects with the apparent horizon, the point H_1 is defined. The angle of depression, ϕ_1 , between the optical axis of the camera and the apparent horizon is determined by:

$$\tan \phi_1 = \frac{PH_1}{f}$$

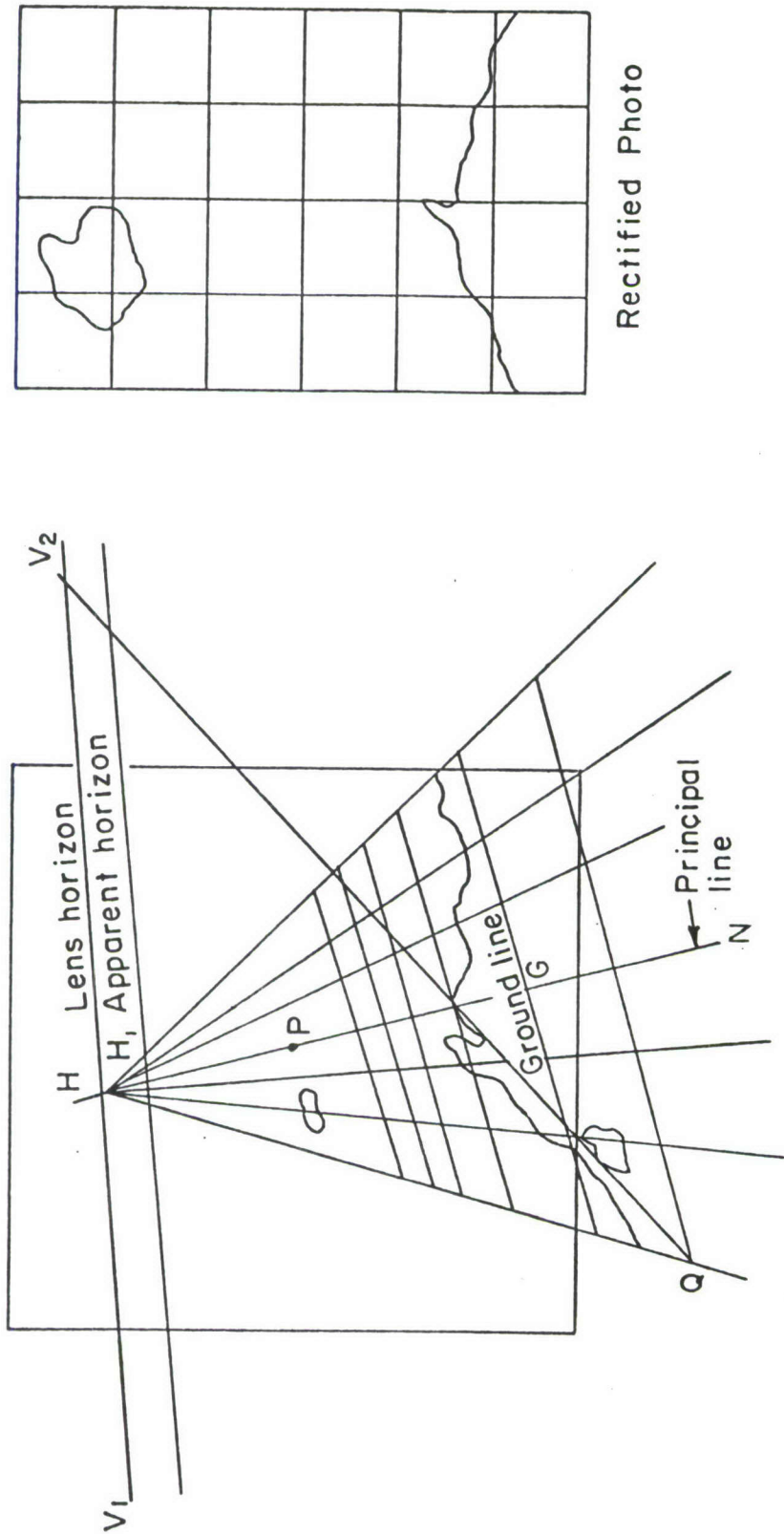


FIGURE 1. PERSPECTIVE GRID METHOD OF TARGET LOCATION

The dip angle, ϕ_2 , between the apparent horizon and the lens horizon is then calculated by:

$$\phi_2 \text{ (in minutes)} = 0.98\sqrt{H} ,$$

where H is the altitude of the camera in feet. The depression angle, ϕ_3 , between the optical axis and the lens horizon is then determined by:

$$\phi_3 = \phi_1 + \phi_2 .$$

The distance PH is then drawn along the principal line from the principal point toward the apparent horizon. Its length is determined by:

$$PH = (f)(\tan \phi_1) .$$

The lens horizon is then drawn as a straight line through the point H perpendicular to the principal line. The vanishing points, V_1 and V_2 , are then plotted as follows:

The distance from H to V_1 and V_2 , the vanishing points of the two systems of horizontal lines which make an angle of 45° with the principal line, is determined by:

$$HV_1 = HV_2 = (f)(\sec \phi_1) .$$

Plot the vanishing points V_1 and V_2 at the distance HV_1 and HV_2 to the left and right of point H along the principal line. The distance from the principal point to the photographic nadir is calculated by:

$$PN = (f)(\cot \phi_1) .$$

Then plot the nadir at the distance PN from P along the principal line away from the apparent horizon. After establishing the position of the vanishing points, the perspective grid lines may be drawn as follows:

The distance from H to a point G is computed by:

$$HG = \frac{H}{S(\cos \phi_1)} ,$$

where $S = f/H$ (focal length/altitude). The point G is then plotted at the distance HG along the principal line from H in the direction of the principal point. The ground line is then drawn through the point G parallel to the lens horizon. The length of the perspective grid interval, w, on the ground line is then computed by:

$$w = W/S .$$

where W is a given ground interval.

The perspective grid interval, w , is then laid off on the ground line to the right and left of the principal line. From the perspective interval points on the ground line, radial lines are then drawn to the point H . From point V_2 a line is drawn to a suitable point near the left corner of the image. A line parallel to the lens horizon is then constructed through the intersection of the line V_2Q with each of the lines radiating from H .

Finally, a square grid is laid out at the desired map scale with each square representing one of the quadrilaterals on the perspective grid. Every point on the photograph can then be plotted very accurately in relation to the grid lines. As noted earlier, it is important that there be little or no relief. The smaller the ground interval, W , the greater the target-location accuracy, since the scale varies quite drastically the closer the target appears to the horizon on the photo.

Two-Camera (Transit) Method

Two identical cameras are set up with an identical orientation and at a known base distance apart. The accuracy of this method will increase as the base distance approximates the camera-to-target distance. Both cameras should be pointed with their optical axes parallel to each other. (A compass may be used to accomplish this purpose.) Figure 2 shows this procedure. The distance from either camera position may then be obtained by measuring the film coordinates and using the Law of Sines.

Film Processing and Film Analysis

Processing of the film may be done in the field, with no more required than a photographic black bag for unloading the film cassettes into the daylight-type processing tank. The high-speed infrared film requires loading and unloading in total darkness. Whatever the size of the original negative, image analysis should be performed on a final image of at least 8 x 10 in. That may be done by viewing the original negative with a projection or microscopic systems which also allows image mensuration. Most likely a darkroom facility will be available to at least produce 8 x 10-in. format paper prints. If a mapping or reconnaissance facility is available, then any mensuration could be performed quite accurately with the equipment typically found in such a facility.

f = focal length of camera
 m = image distance on photo of Camera I
 n = image distance on photo of Camera II

$$\Delta a = 90^\circ - c$$

$$\Delta b = 90^\circ - d$$

$$\Delta \phi = 180^\circ - (90^\circ - c) - (90^\circ - d) = c + d$$

AB = known distance between identically oriented cameras

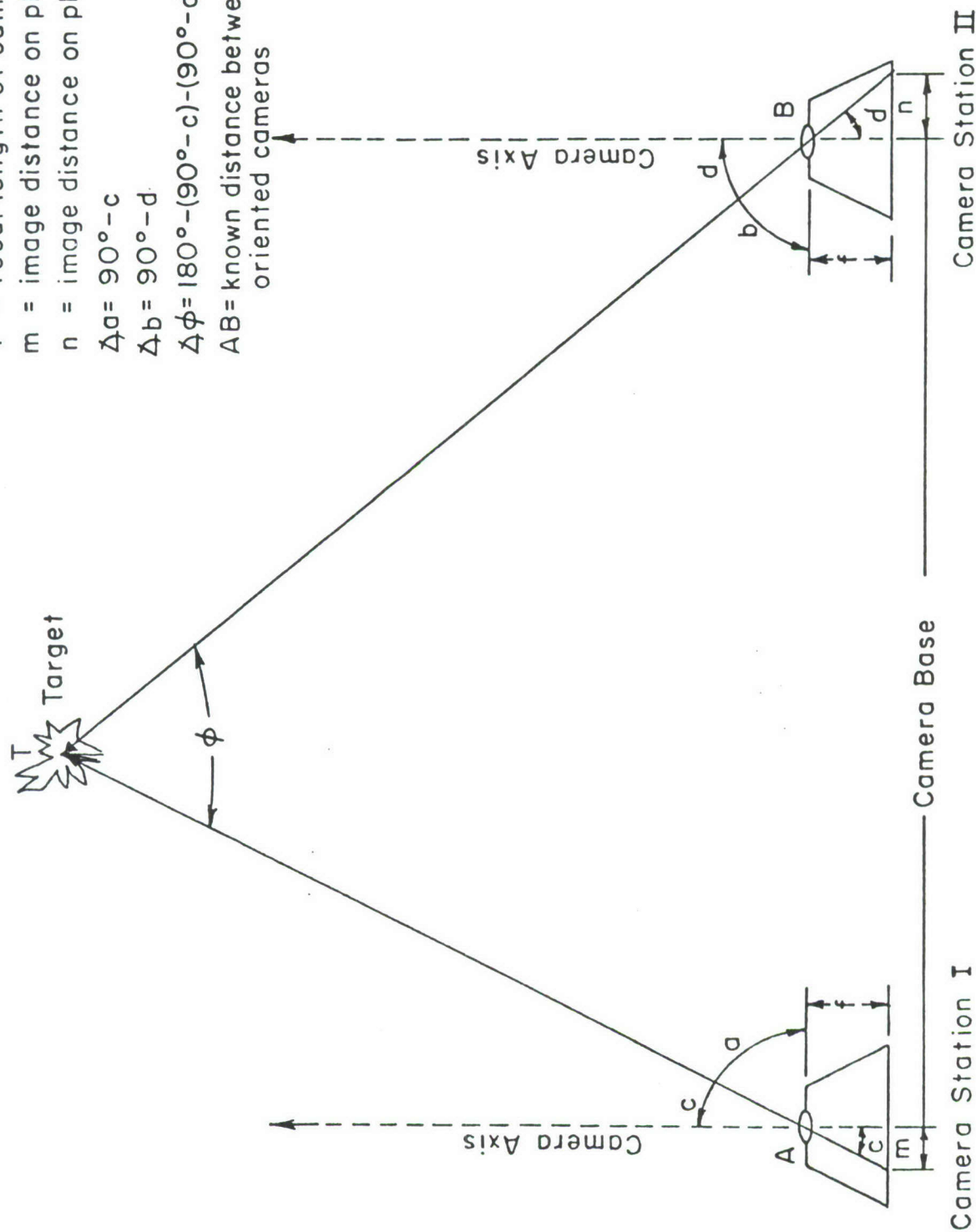


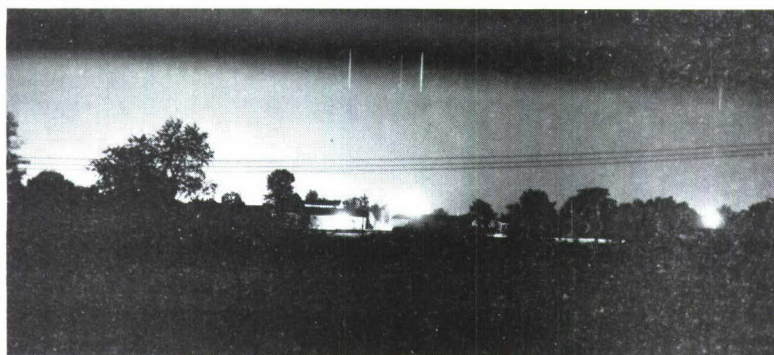
FIGURE 2. TWO-CAMERA (TRANSIT) METHOD OF TARGET LOCATION

Assuming that a 35-mm camera is pointed at a target some 10 miles away, then an 0.5-mm image in the center of the photo would define a target some 500 feet in diameter. Since a good camera setup should be sensitive to resolving images at least 20 times that small, it is probable that muzzle flashes will be detected, provided they are bright enough to be seen normally with the unaided eye. Exposing the same photographic frame to several such flashes would definitely increase the brightness of the recorded image.

It is entirely possible that such techniques could be established as to permit mensuration of the muzzle-flash location within 2 to 10 minutes of its occurrence. This would be done by using a Polaroid film or large-format photographic film sheets on which measurements could be made while still wet from processing.

Experiment and Analysis

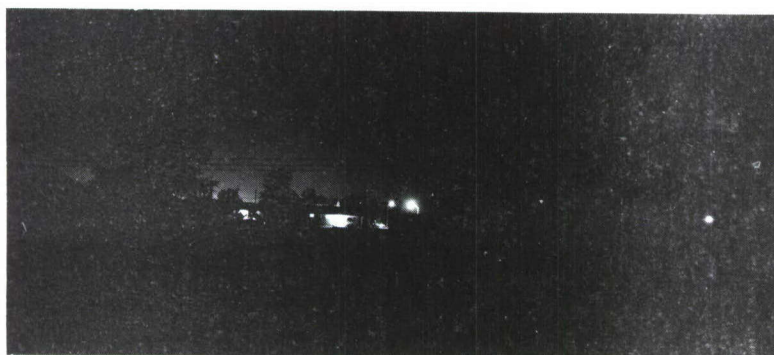
An experiment was conducted with Polaroid and high-speed IR film to determine the detectability of each and to determine how long photographic exposures may be made on one film frame at night (see Figures 3 and 4). A 4 x 5-in. view camera with a 150-mm lens and a 35-mm camera with a 49-mm lens were used. The lights to be photographed were from 3/4 to 1 mile from the camera stations. The view camera contained the Polaroid film and the 35-mm camera the high-speed IR film. Exposures were made at f/4.5 between 1/400 second and 15 minutes with the 4 x 5-in. camera and at f/1.4 and f/16 between 1/1000 second and 15 minutes. The sky proved to be considerably illuminated from the lights of the city of Columbus as can be seen in the 10- and 15-minute exposures in Figure 3.



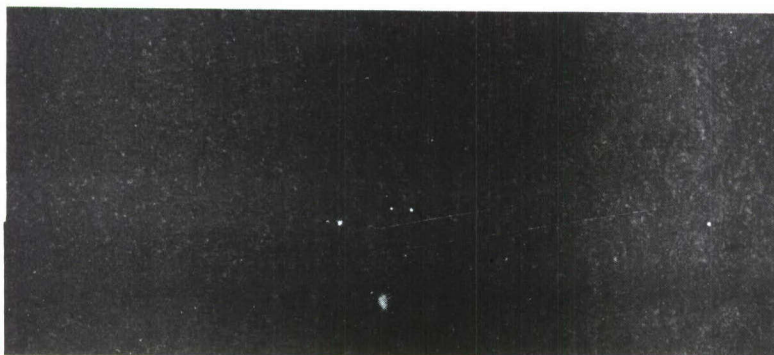
15 minutes



10 minutes



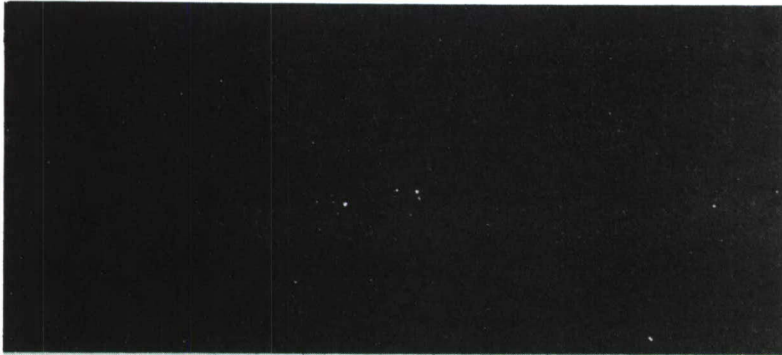
1 minute



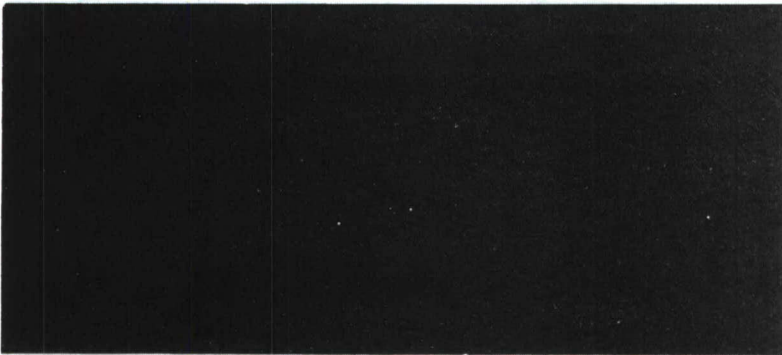
1 second

FIGURE 3. POLAROID PHOTOGRAPHS MADE WITH
4 x 5-IN. VIEWING CAMERA

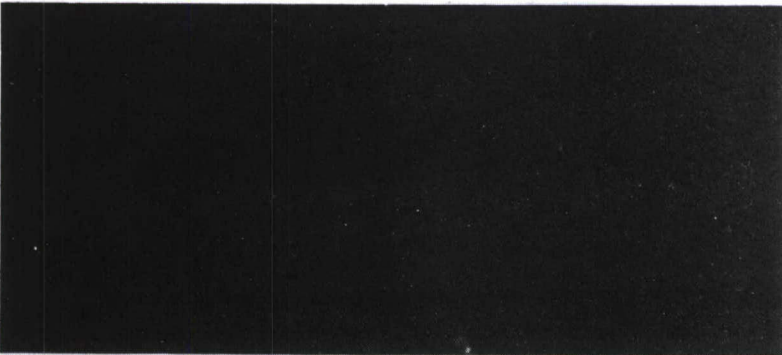
A 150-mm lens was used and exposures
were at f/4.5 for time indicated.



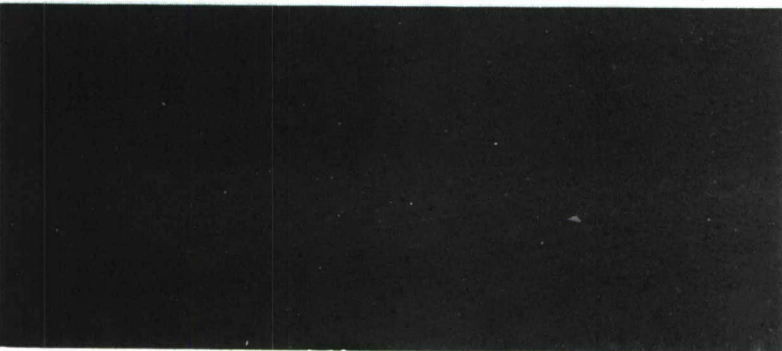
1/5 second



1/25 second

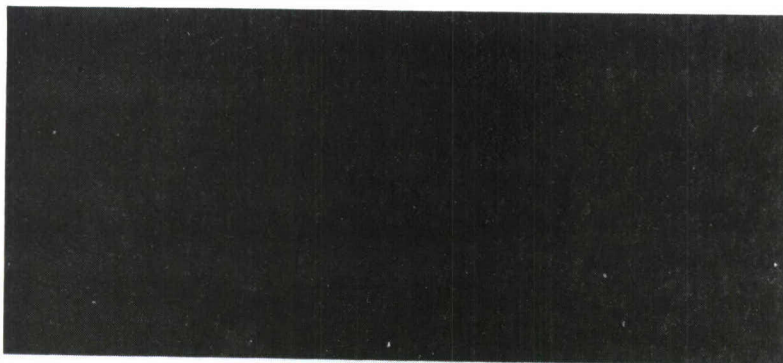


1/50 second

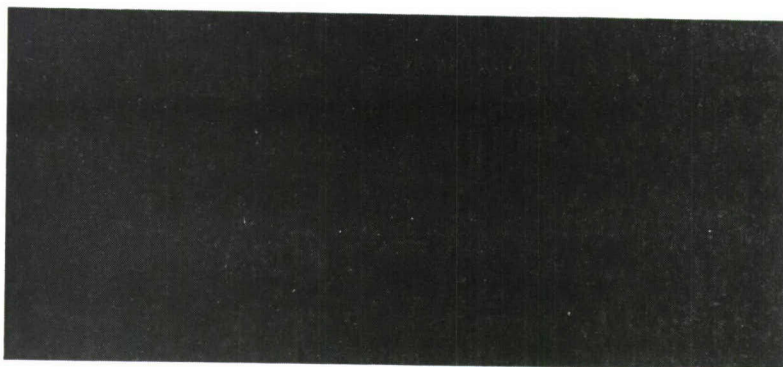


1/100 second

FIGURE 3. (Continued)



1/400 second



1/400 second
(exposed 5 times)

FIGURE 3. (Continued)



15 minutes



10 minutes



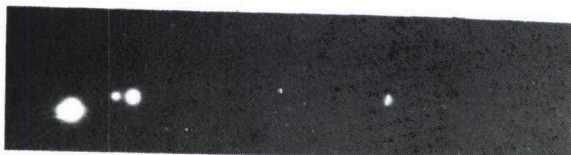
1 minute



1 second

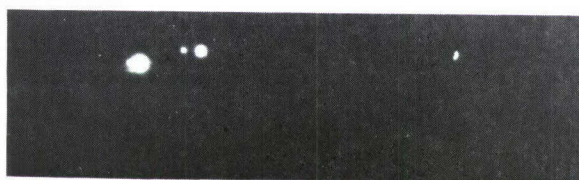


1/2 second

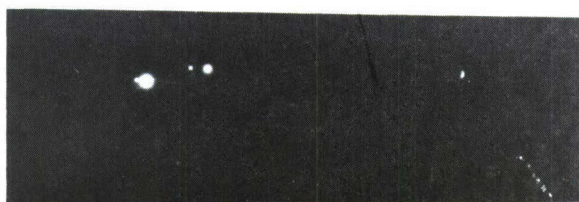


1/4 second

FIGURE 4. PHOTOGRAPHS MADE WITH 35-MM IR FILM
Exposures were at f/16 for time indicated.



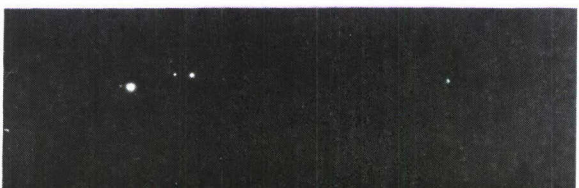
1/8 second



1/15 second



1/30 second



1/60 second



1/125 second



1/250 second

FIGURE 4. (Continued)

An examination of the 35-mm IR negative and a comparison with the Polaroid film yielded the following information. Both films are fast enough to detect light sources several miles from the camera station. The photographed light sources were a yellow 60-watt bulb on a house and one incandescent and fluorescent streetlight. The fact that a photographic impression was made at speeds of as much as 1/1000 second and f/16 is indicative of the probability that a muzzle flash, which would be at least as bright as sources described here and of relatively much longer duration, would be recorded on a photographic film exposed through a fully open lens.

The IR film proved to be from 2 to 5 times more sensitive and may be even more sensitive with hotter light sources than photographed here. All three light sources were recorded on every exposure made with both cameras. (Since the viewing camera was restricted to a lens opening of f/4.5, and since the shortest exposure possible was only 1/400 second, it could not be as severely tested as the IR film.)

Through various types of lights (such as the lights of a city) are recorded during long exposures, the areas near the ground where muzzle flashes would appear are sufficiently dark to record any light sources there quite vividly. Repeated exposure of the same light results in a brighter image.

CONCLUSIONS AND RECOMMENDATIONS

It appears entirely feasible at this time that a brief field test would result in the development of a method which would provide the detection and location of artillery muzzle flashes, provided these are bright enough to be seen with the naked eye.

We suggest that a test be conducted on an artillery firing range at night under conditions typical of those in the field. An outline for the test could be provided, and if desired, the test could be conducted by Battelle personnel or supervised by them. Analysis of the film would be made under field conditions to determine how quickly photogrammetric techniques result in locating one or more artillery positions. It is estimated that a task involving such a field test would require a 3/4 to 1 man-month effort, including the writing of a report of the results.

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- (3) McNeill, G. T., Photographic Measurements, Pitman Publishing Corp., New York (1954).
- (4) Engineering Design Handbook, "Spectral Characteristics of Muzzle Flashes", AMCP 706-255, Headquarters, US Army Materiel Command (June 1967).
- (5) Griffin, E. P., et al., Photogrammetric Applications to Field Artillery, US Army Engineering Topographic Laboratories, Fort Belvoir, Virginia (March 1970).

APPENDIX I

APPENDIX I

On 14 February 1973, Dr. J. G. Stephan and Mr. J. Wenig (US Army Land Warfare Laboratory), photographed 105mm artillery muzzle flashes at Ft. Sill, OK. The guns were located two miles from the camera. The muzzle flashes were not visible to the eye although flashlights used by the gun crew were easily seen. There was almost a full moon during the test. These tests were conducted between 4:30 pm and 9:00 pm. The photos were taken with Kodak infrared film. These photos are included as Figures 1-7. It is important when examining the photos to distinguish between the camp lights which were recorded for several minutes on the film while the shutter was open and the muzzle flashes which were recorded in only a fraction of a second. The 70mm photos were taken with a Hasselblad camera using a 100mm lens. The 35mm photos were taken with a Pentax camera using a 50mm lens. All photos with the infrared film were taken using an 87C filter. Figures 5 and 6 have been processed with a Model 703-32 Spatial Data Color Encoder/Viewer. This system converts density differences into color differences. It can discriminate 400 different steps in density, color encoding 32 at a time.

Gun Position Vacant



Figure 1. A 35mm Enlargement of Plus X Film taken at 4:45 p.m. of the General Area with the Battery Still Absent.

Gun Position



Figure 2. A 70mm Enlargement of Plus X Film Taken at 5:30 p.m. With the Battery
Drawn up on Line.



Figure 3. A 35mm Enlargement of High-speed IR Film Taken Between 7:30 and 8:00 p.m.
Showing 2 Muzzle Flashes in the Artillery Location.

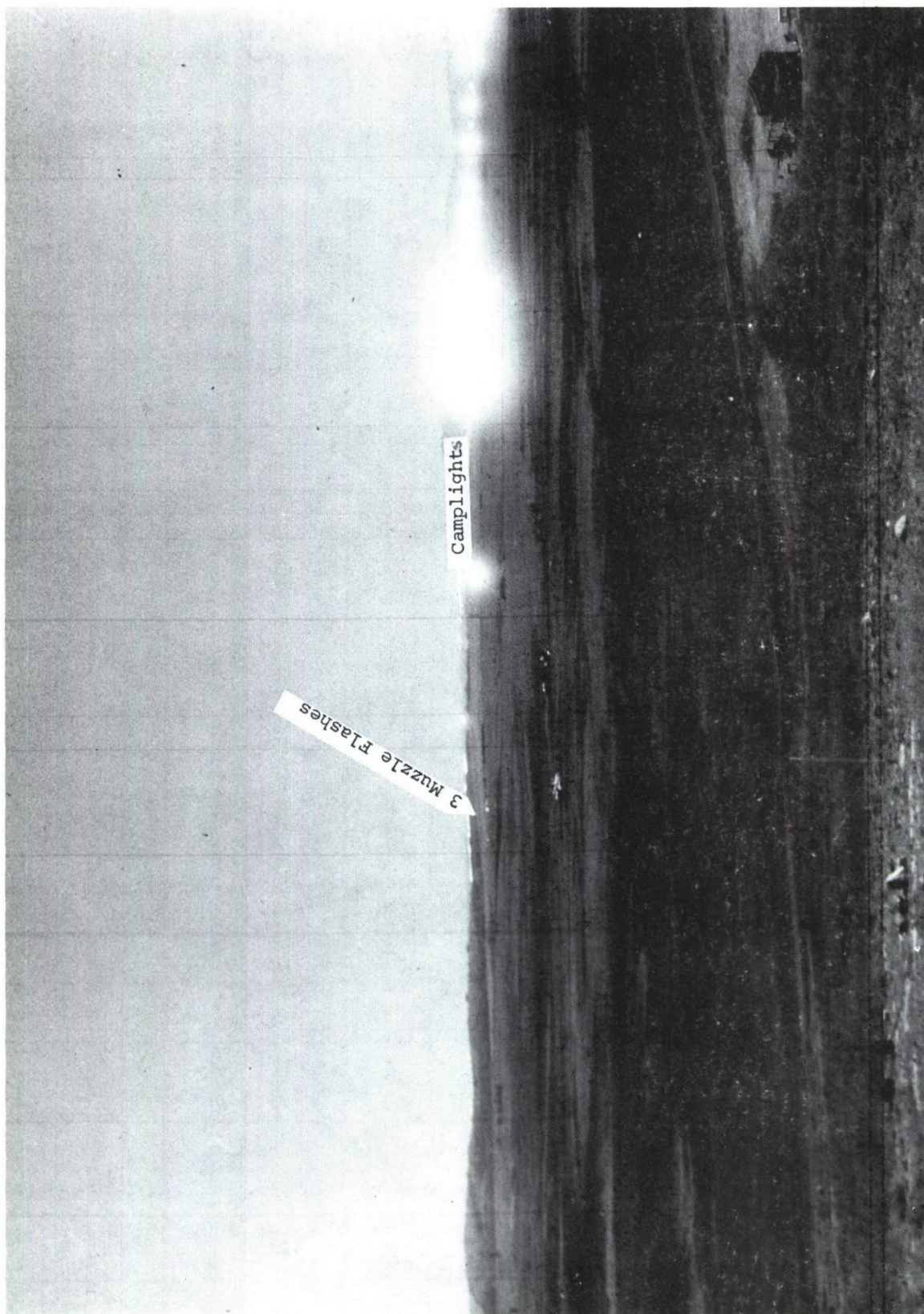


Figure 4. A 70mm Enlargement of High-speed IR Film Taken Between 7:40 and 8:15 p.m. Showing 3 Muzzle Flashes in a Somewhat Different Location, Two of Similar Magnitude, and One Several Times More Prominent.



Figure 5. An enhancement of 70-mm IR film on a 703-32 Spatial Data Color Encoder/Viewer; the muzzle flashes have been encoded in white.

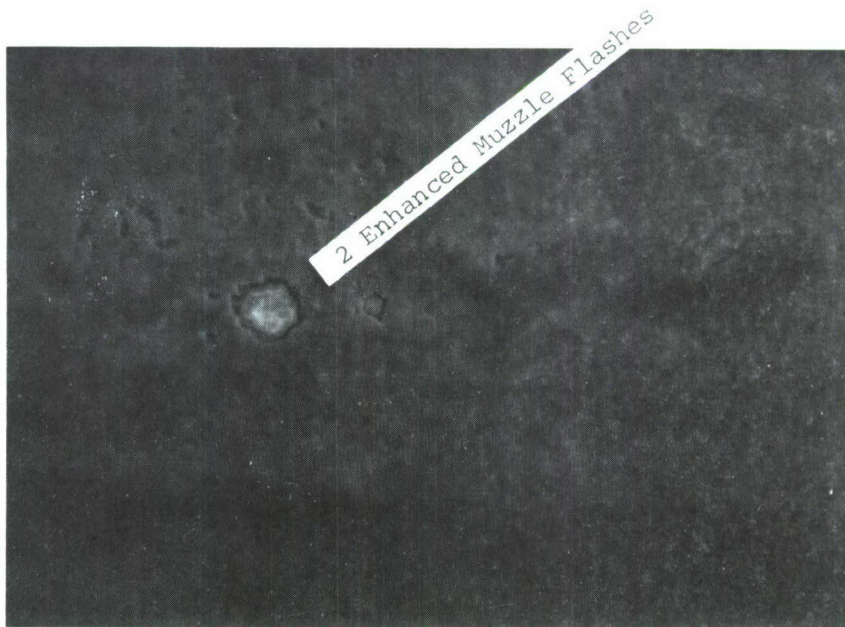


Figure 6. An enhancement of 75-mm IR film on black and white background, with the muzzle flashes encoded in white, yellow, and blue.

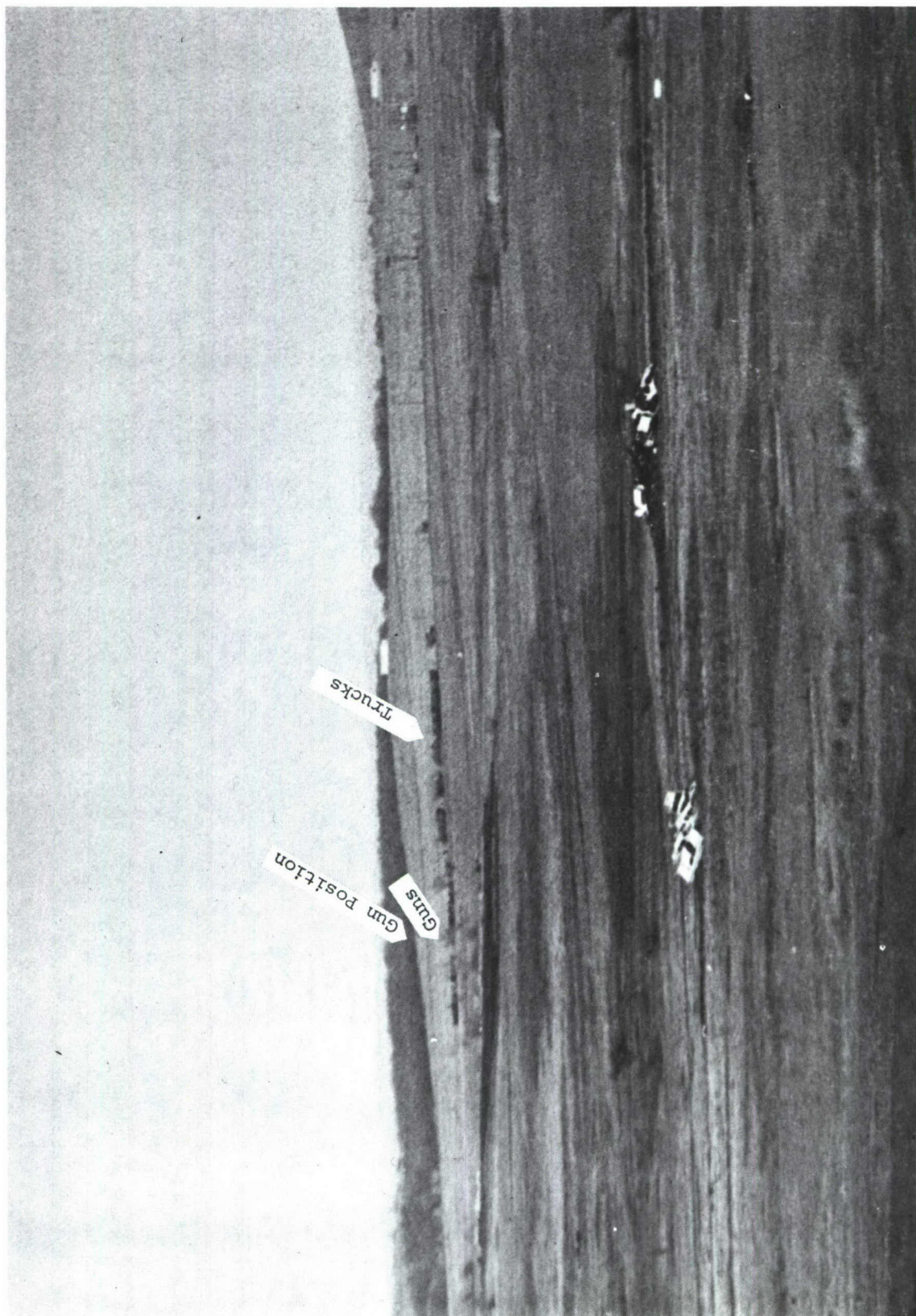


Figure 7. A Close-up View of the Artillery Positions (a further enlargement of Figure 2).

APPENDIX II

APPENDIX II

A series of photos were taken at Aberdeen Proving Ground by Mr. H. C. McDowell (US Army Land Warfare Laboratory) on 2 Aug 73 between 8:30 pm and 10:15 pm. The photos were taken with Kodak HIE 135 infrared film. The gun was 105mm, M68 tank gun. It should be noted that the normal propellant charge for the 105mm tank gun is approximately four times that of the 105mm howitzer. The photos were taken normal to the trajectory directly out from the tank at a distance of 840 ft. For these firings the gun crew blew a warning whistle then ten seconds later blew the whistle again and fired the gun almost simultaneously. The camera shutter was opened at the first whistle and closed after the firing. The film was developed in Kodak D-76 developer. A TOPCON Super D camera with a #87 filter was used to take these photographs. Two of the photos are included here as Figures 1-2.

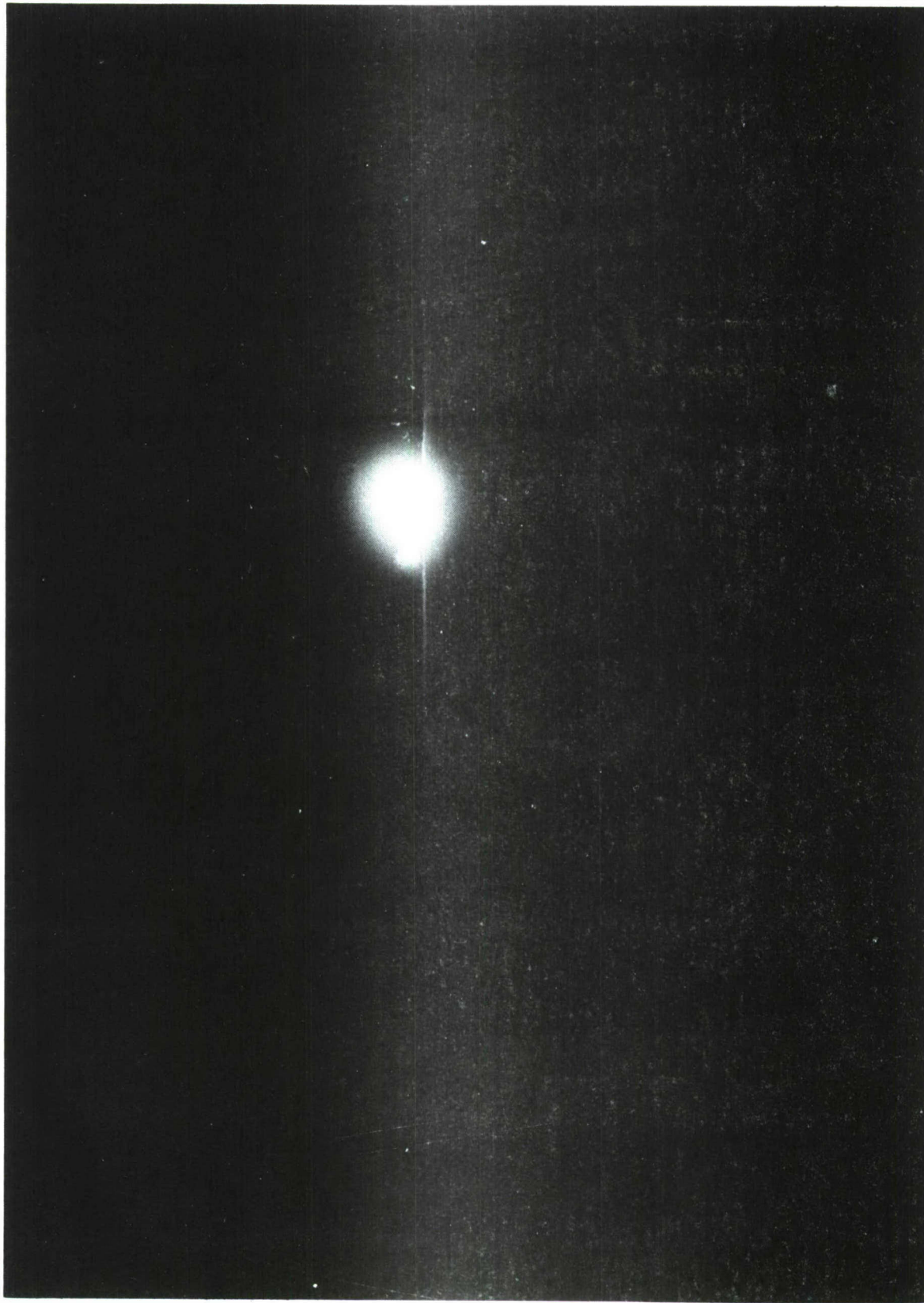


Figure 1. Photo of 105mm Tank Gun Muzzle Flash - f16 Shutter Opening.

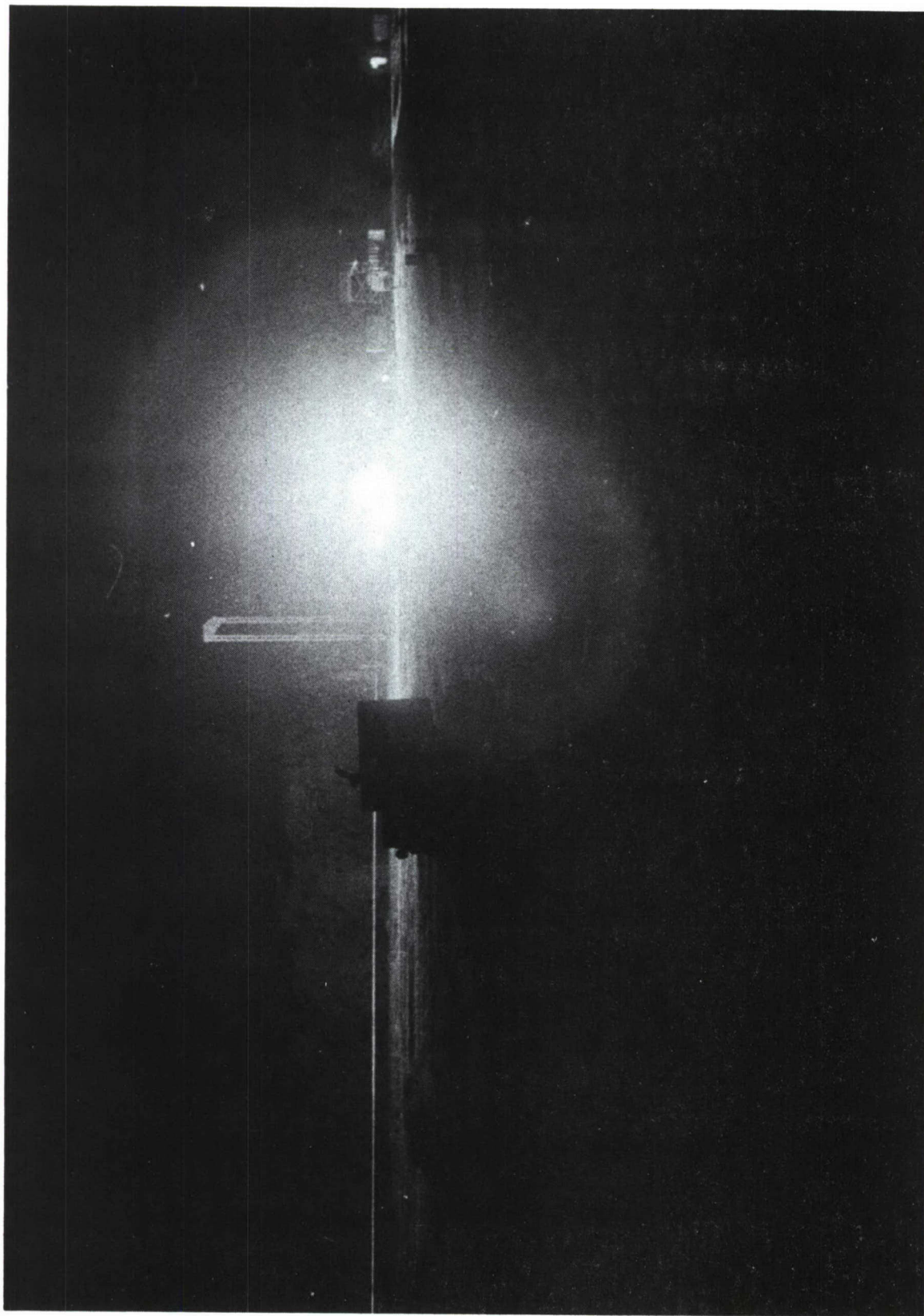


Figure 2. Photo of 105mm Tank Gun Muzzle Flash - f2.8 Shutter Opening.

APPENDIX III

TV CAMERA APPROACH

It is recommended that an extended range television camera, sensitive to the IR be considered for this application. Nonblooming tubes with adequate near IR response out to 1.1μ are available. These cameras are inexpensive and usually use a silver target mosaic tube. The addition of a deep red filter should permit detections under daylight conditions. A filter insertion loss of an order of magnitude could be tolerated while still maintaining an adequate response. The continuous scanning feature and wide field-of-view of the TV system overcomes several of the obvious deficiencies of the camera/film approach. Some of the advantages of this system are:

- (1) Immediate real-time response.
- (2) The picture is renewed with each raster scan eliminating saturation exposure due to continuous background sources.
- (3) No lost time between photos.
- (4) Instantaneous source location by observing TV picture of area without filter.
- (5) Data may be stored on video tape for replay. Tape can be erased and reused later.

With a relatively simple field test it should be possible to establish the feasibility of this approach to artillery locations.

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